Influence of Data Flux on System Integration

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Abstract. With customers demanding more and more holistic answers to their problems, solution providers respond with complex systems, integrating product, service and ICT elements into their offer. These solutions need to be aligned to a high number of requirements, coming not only from the individual customer but also from an environment of network partners, technology providers and other stakeholders. Especially for Product-Service Systems, where the solution provider takes responsibility in the operational phase, this environment is dynamic over the system life cycle. Stakeholders may enter or leave, as well as changing needs and technological capabilities. This makes the requirements towards the solution volatile, demanding a suitable Requirements Engineering approach. In this paper, it is discussed how environmental dynamicity can be monitored for its effect on requirements, with a special focus on organizational issues. Through a literature review and industrial case studies it is analysed, how it can be ensured that environmental changes can be taken into account in Requirements Engineering, leading to an optimal system configuration to address the customer problem.

Keywords: Requirements Engineering · Dynamic environment · ProductService System · InnoScore Service · Focus Activity Model

1 Introduction

Within the last decades customers increasingly demand holistic solutions for their individual problems, and their procurement is driven by the expected benefits from using the solution rather than sales price only [1]. Consequently, solutions are becoming

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complex systems that have to be aligned to an environment of stakeholders, technology and constraints. In the case of Product-Service Systems (PSS), where the solution provider is responsible for the whole life cycle of the system, including operation and evolution [2], this environment is dynamic. Stakeholders, application scenario and available technologies will change over time.

Following these developments, the main prerequisite for a high quality solution is understanding the underlying needs, and thus the requirements for the system throughout its entire life cycle [3]. The effects of environmental dynamicity on the requirements for the system have to be taken into account for Requirements Engineering (RE); i.e. constantly monitoring the changes of stakeholders, needs or newly available technologies and adapting the requirements accordingly. The need for developing models, modelling methods and tools supporting RE for complex systems, such as PSS, has been claimed by several authors [4–7].

The objective of this paper is to discuss the effects of environmental dynamicity on RE for complex systems like PSS. How can it be monitored, and how can the influence of changing stakeholders and technology on the requirements for the solution be managed? After defining the research question and methodology in the next chapter, a literature review on the challenges of RE for complex systems in dynamic environments is presented in the third chapter. Based on this, Sect. 4 presents two approaches to monitor environmental dynamicity, which are applied in industrial use cases. Finally a summary and research outlook is given.

2 Methodology

The main research question to be addressed in this paper is how to monitor dynamicity in the stakeholder and technological environments of for complex systems, such as PSS, and feed the results back into the RE process?

In order to answer this question, the authors have conducted a literature review to understand the research gaps and challenges. To perform this state-of-the art investigation, the authors have performed a search through the scientific databases “Google Scholar”, “Scopus” and “Research Gate”, using key words combinations to address the specific topic of interest: “RE AND Systems Engineering”, “Product Service Systems Requirements Engineering”, “Requirements Engineering for complex systems”, and “Requirements Engineering + PSS”. The search has been targeting specifically the Title, Abstract and Key Words of the documents. Papers collected were then screened and selected by the analysis of their abstract.

Furthermore, the researchers have been involved in the specification and development of PSS scenarios in several industrial use cases during the last two years. More specifically, action research was applied [8], conducting multiple on-site workshops with representatives from different departments. During this work, two approaches were developed and tested to monitor changing environments: Innoscore Service and FocusActivity Model.

3 Requirements Engineering for Complex Systems in Dynamic Environments

This chapter presents the outcome of the literature review, first showing the shift of complex system RE preferences in general before deriving the challenges for RE in dynamic environments more specifically.

3.1 Shift of Requirements Engineering Preferences

RE for complex systems in dynamic environments has to be able to coordinate effectively among stakeholders, while envisioning future needs and technological opportunities in the process. Svetinovic [4] has called such an approach “Strategic RE” and highlights four conceptual shifts of RE preferences in the system perspective by analysing the characteristics of complex sustainable systems and the challenges in their design process and combining them with the mechanisms of RE (see Fig. 1).

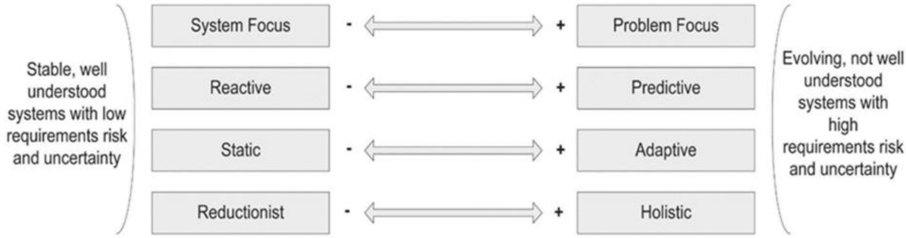

Fig. 1. Strategic shift of RE preferences for complex systems [4]

As can be seen, first it is important to focus on the problem, instead of the system functionality. As the problems are initially not well defined, it is imperative to define clearly all the requirements aligned with the system environment. Furthermore, as the system environment will change, RE methods have to predict future requirements arising from the system's interaction with the environment. Connected to this, the system has to be adaptive to unforeseen changes through feedback during system operation without the necessity for costly re-development and prototyping. Finally, RE must follow a holistic perspective of the system and its environment. Moreover, the author highlights the necessity to analyse the interactions and to adapt the requirements within the context [4].

A suitable RE methodology has to support the management of unstable and unknowable requirements, taking into account information from all system life cycle phases [9]. This is in line with the openness to change and attention to uncertainty management for complex systems. Regarding a long-term perspective, no specific approach is provided within RE methodologies. Such considerations e.g. for future PSS are not strongly addressed or allowed by specific tools enabling, for instance, to contemplate future requirements rising beyond the current ones.

3.2 Implications of Dynamic Environments for Requirements Engineering

Berkovich [7] and Aurum and Wohlin [6] have focused on the importance of the assessment and management of requirement changes during the RE process and the necessary engagement of customers and stakeholders for the effectiveness of tailored solutions. Wiesner et al. [9] have defined collaboration and interoperability between stakeholders and PSS components from different domains, especially products, services and software, and the management of unstable and unknowable requirements, taking into account information from all PSS life cycle phases as key challenges for RE. These works show that RE for complex systems in dynamic environments has to take into account several issues. Three main challenges can be identified:

- All internal, external, primary, secondary **stakeholders** have to be identified for RE, considering possible future scenarios.
- Impacts and effects to and from the environment should be considered for RE, suchas newly available **technologies**.
- **Future requirements** should be proactively predicted for RE, with a long-term view on the suitability of the system.

4 Approaches to Monitor Environmental Dynamicity in Requirements Engineering for Complex Systems

Following the shift of RE preferences for complex systems and the implications of dynamic environments, in a first step solution providers must be enabled to monitor the stakeholder and technological environment to be able to predict future requirements. Jarke et al. [10] propose to consider the relationship between requirements and their business context, also during their implementation process, concluding that only systems embedding an adequate, flexible, and evolvable world-model are likely to survive. Nemoto et al. [11] also recognise the value of context in system design in a framework which allows to draft a macro environment around the customers from the long termglobal environmental context elements. Consequently, strategic tools are needed that allow providing a more complete and deeper consideration of all meaningful influences provided by external elements on the development of a complex system. Two different approaches to monitor a dynamic stakeholder and technological environment of complex systems have been tested by the researchers in industrial use cases: the Innoscore Service and the Focus Activity model. These instruments can give system developers a guideline for including environmental effects into the set of requirements to develop a complex system, as described below.

4.1 Innoscore Service

An approach to consider the environmental situation against the organizational capabilities of the system provider is the “InnoScore® Service” tool which is based on the EFQM-model [12–14]. It is an online tool for measuring, evaluating and improving strategic innovation in manufacturing firms to offer complex Product-Service Systems against their competitive environment [15–18]. The tool is currently available in German for various types of manufacturing companies and takes between 15 and 20 min to complete. Nine different aspects are analyzed and compared to an environmental benchmark based on 126 companies from the plant and engineering sector in Germany. The detailed evaluation of these environmental aspects enables the company to adapt its innovation strategy and derive additional requirements for the development of ProductService Systems [19, 20]. The individual aspects are discussed in more detail below.

By assessing the “Structure and Network”, “Skills and Knowledge”, as well as “Innovative Culture” of the environment, it can be determined if all relevant stakeholders are considered for PSS development. Observing the “Technology”, and “Market” aspect helps to define the technological context of the solution, thus taking into account changes that might happen in this environment. The aspects “Product and Service”, “Strategy” and “Process” examine processes, such as RE, that must be built up and further developed in a targeted way [21–23]. Figure 2 shows an exemplary evaluation of a company, where the aspect “Technology” is very good in comparison to the benchmark, while the aspect “Skills & Knowledge” should be improved. This might indicate to re-assess the stakeholder environment to derive requirements from additional actors for system development.

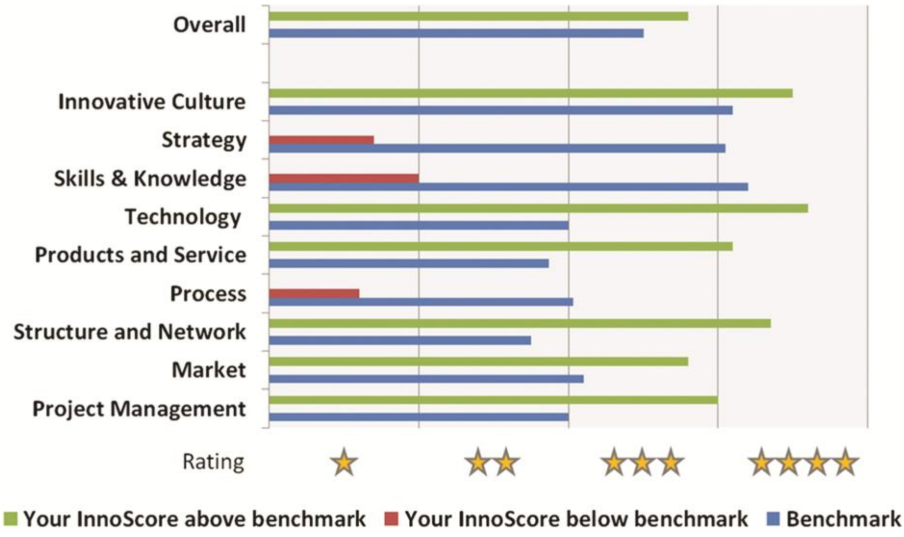

Fig. 2. Screenshot of the evaluation of an example company [18]

While the Innoscore Service is not able to provide changing requirements automatically to the RE process, it helps to understand the relationship between the environment and the innovation strategy. A periodic application of the tool helps to identify new stakeholders and technology and derive new requirements accordingly.

4.2 Focus-Activity Model

The Focus Activity model has been proposed within the PSYMBIOSYS European project as a mean for mapping innovation needs for implementing PSS in a company. It enables a company to position its product and service business separately along a structural and a cooperation dimension. The "Structural Focus" indicates how much a company is oriented on product or on service business, based on factors such as strategy, network or capabilities. "Cooperation Activity" refers to the level of proactive collaboration during PSS design, with the appropriate interfaces, information and roles [24].

Between the high and low values for both dimensions, four types are distinguished in Fig. 3 below. This figure illustrates a company increasing its service focus, while at the same time improving cooperation in product and in service (Type III → Type I).

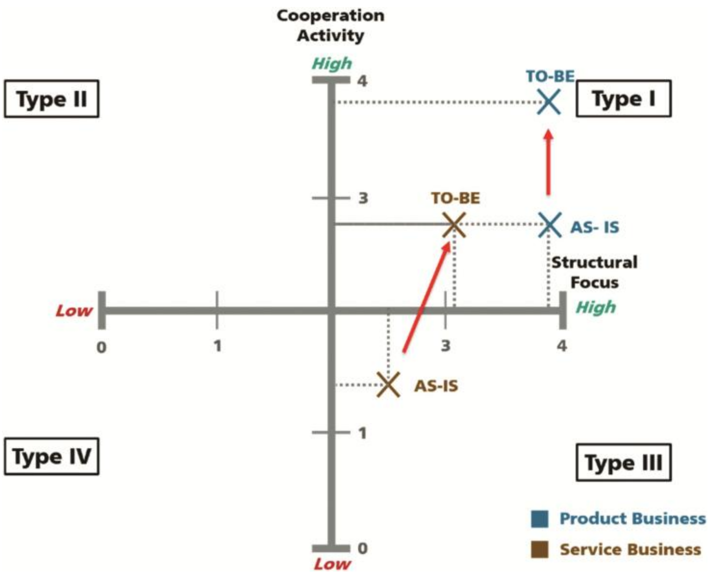

Fig. 3. Example of Focus Activity Model

The movement of the product or service business along the axes and between the different types illustrates intended or actual changes in the organizational environment of a complex system. Thus, it can provide a simple vision of different future scenarios for deriving changing requirements in the RE process. By including the product and service related stakeholders (“Network”), inconsistent requirements and trade-offs can be identified for PSS development. Furthermore, new technological capabilities or interfaces might lead to new requirements to be considered for system design. Like the Innoscore Service, the Focus Activity model cannot automatically provide requirements to RE. However, it helps to develop future PSS scenarios as a basis to discover new requirements.

5 Conclusions and Future Work

Engineering of complex systems is evolving from a temporal development process for individual solutions towards a permanent orchestration of distributed product, service and ICT elements adapted to a dynamic environment, which has to be observed by RE. Based on a literature review, a predictive, adaptive and holistic approach with a problem focus has been identified as the new preference for RE. Three environmental aspects have been identified as important: changing stakeholders from different application scenarios, constant feedback on new technologies or capabilities, and prediction of future requirements for the system.

Two high-level approaches to monitor these aspects have been tested with industrial use cases. While not being specifically designed to support RE, results from the use cases indicate that useful conclusions can be drawn from their application. The Innoscore Service approach provides a feedback on the industrial benchmark for several environmental aspects to derive requirements accordingly. The Focus Activity model helps to develop future PSS scenarios and discover related requirements.

Both approaches are limited to an organizational level and do not automatically provide requirements to RE. Thus, in future research, the authors aim to formalize their application, so that they can be included into a RE methodology for complex systems in dynamic environments. In addition, the inclusion of sensors and communication capabilities into systems could provide the opportunity to monitor directly the environment. Big data analysis of operational data or the users' sentiments would help to automatically detect changing requirements and adapt the PSS accordingly.

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